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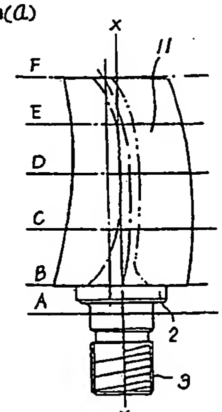
(54) Rotor blade of axial-flow machines.

(57) The known rotor blade of axial-flow machines is improved. The improvement resides in a novel configuration of the respective blades in the rotor. The leading edge of the tip end portion of each blade tilts forwards to the upstream side, and also advances in the direction of rotation. In the tip end portion, between the tip end surface and a cross-section displaced from the tip end surface towards the central portion by 1/2 of a chord length, the configuration of the leading edge of the tip end portion is such that the angle S of skew direction of the leading edge of the tip end portion in the direction of rotation and the effective skew amount θ_s eff in the direction of the leading edge of the tip end portion tilting forwards to the upstream side fall in a particular region in a diagram of S vs. θ_s eff delimited by specific 4 points A, B, C and D determined through experiments.

Fig. 1(a)



ROTOR BLADE OF AXIAL-FLOW MACHINES

BACKGROUND OF THE INVENTION:

Field of the Invention:

The present invention relates to a rotor blade of axial-flow machines for giving energy to fluid or being given energy from fluid such as axial-flow blowers, axial-flow compressors, axial-flow pumps, axial-flow gas turbines, etc. (throughout this specification and claims, these machines are generally called "axial-flow machines").

Description of the Prior Art:

At first, a structure of a rotor blade of an axial-flow machine in the prior art will be described with reference to Fig. 6. In Fig. 6(a), reference numeral 1 designates a blade body of a rotor blade, numeral 2 designates a platform (flange portion), numeral 3 designates a screw portion, and the rotor blade body 1 is fixedly secured to a hub not shown by means of the platform 2 and the screw portion 3. In lieu of the screw portion 3, a fixing method by making use of a dovetial could be employed. The respective cross-section profiles taken along cross-sections A - F perpendicular to the radial direction of the hub of the blade body 1 are as shown in Fig. 2(c), and the points denoted by numeral 5 in this figure are centers of figure of the respective cross-section profiles. In addition, reference character Y designates the direction of an airflow, and reference character R designates the direction of rotation of the blade body 1.

The blade body 1 of a rotor blade in the prior art had the centers of figure 5 of the respective cross-section profiles aligned on a same straight line, and numeral 6 designates a centroid which forms a straight line and aligns with the radial direction of the hub. The reason why the respective centers of figure 5 are made to align with a same radial direction of the hub, is for the purpose of causing an unnecessary stress not to be generated by a centrifugal force acting upon the rotor blade, and if the centers of figure 5 should not align on a straight line, a moment directed in other directions than the radial direction of the hub would be generated by the centrifugal force, and a bending stress would act upon the rotor blade. However, if the centers of figure 5 align on a same radius of the hub, then theoretically only a tensile stress must act upon the rotor blade. (It is to be noted that, in practice, a bending stress caused by compressed gas as well as a torsion stress caused by torsion of the respective cross-section profiles would be also generated.) In this way, the structure of the rotor blade in the prior art was decided only from a view point of mechanical strength.

As described above, in a rotor blade of, for instance, an axial-flow compressor in the prior art, a structure of a rotor blade was decided only from a view point of mechanical strength, and provision was made such that the respective centers of figure 5 of the cross-section profiles of the blade member 1 may align on a same radius of the hub. However, at the tip end portion of the blade member 1, that is, at the portion close to the inner surface of a casing, turbulent complicated flows are formed as a result of drift by centrifugal forces of a boundary layer along the inner surface of the casing and a boundary layer along the blade surface, or gathering of secondary flows between the respective blade bodies, hence fluid having low energy is liable to stagnate, resulting in deterioration of the action of the blade body 1, and a pressure loss of the flow at that portion is larger than that of the flow at the central portion of the blade body 1 (a principal flow). Consequently, an efficiency of the rotor blade is lowered.

SUMMARY OF THE INVENTION:

It is therefore one object of the present invention to provide an improved rotor blade of axial-flow machines, in which the aforementioned problems of the rotor blade in the prior art are resolved.

A more specific object of the present invention is to provide a rotor blade of axial-flow machines, in which a large pressure loss at the tip end portion of a blade body is reduced and thereby an efficiency of the rotor blade is enhanced.

According to one feature of the present invention, there is provided a rotor blade of axial-flow machines comprising a blade body, in which a leading edge of a tip end portion tilts forwards to the upstream side

and also advances in the direction of rotation, and the configuration of the leading edge of the tip end portion between a tip end surface of the tip end portion and a cross-section displaced from the tip end surface towards the central portion by 1/2 of a chord length is such that an angle S of a skew direction of the leading edge of the tip end portion in the direction of advance along the direction of rotation, and an effective skew amount θ_s eff in the direction of the leading edge of the tip end portion tilting forwards to the upstream side may fall in the region delimited by the following 4 points A, B, C and D:

	A	B	C	D
S	90°	50°	50°	90°
θ_s eff	4°	12°	21°	27°

In the rotor blade of axial-flow machines according to the present invention, in order to reduce a large pressure loss especially at the tip end portion of a blade member and improve an efficiency of the rotor blade, the configuration of the tip end portion of the blade member is sought for experimentally, thus the leading edge of the tip end portion of the blade member is made to tilt forwards to the upstream side and also advances in the direction of rotation so that the configuration of the leading edge of the tip end portion of the blade body may fall in the above-specified region, and therefore, fluid having low energy which is liable to stagnate at the tip end portion of the blade body can be forced to flow towards the downstream without stagnating at the tip end portion.

The above-mentioned and other objects, features and advantages of the present invention will become more apparent by reference to the following description of preferred embodiments of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS:

In the accompanying drawings:

Fig. 1(a) is a side view of a rotary blade of an axial-flow compressor according to one preferred embodiment of the present invention;

Fig. 1(b) is a plan view of the same;

Fig. 1(c) is cross-section views of the same taken at six different positions;

Fig. 2(a) is a schematic view of the same;

Fig. 2(b) is a schematic view of a rotary blade of an axial-flow compressor in the prior art;

Fig. 3 is a diagrammatic view of rotary blades of axial-flow compressors according to the aforementioned preferred embodiment and in the prior art;

Fig. 4 is a diagram showing the region of an angle S of the skew direction and an effective skew amount θ_s eff of a rotary blade of an axial-flow compressor according to the above-mentioned preferred embodiment;

Fig. 5 is a side view of rotary blades of axial-flow compressors according to other preferred embodiments of the present invention;

Fig. 6(a) is a side view of a rotary blade of an axial-flow compressor in the prior art;

Fig. 6(b) is a plan view of the same; and

Fig. 6(c) is cross-section views of the same.

DESCRIPTION OF THE PREFERRED EMBODIMENTS:

Now, one preferred embodiment of the present invention will be described with reference to Figs. 1 to 4. Referring to Fig. 1, a rotor blade of an axial-flow compressor according to the present invention is designed in such manner that fluid having low energy which is liable to stagnate at a tip end portion of a blade body 11 may be forced to flow towards the downstream in order to improve an efficiency of the rotor blade by reducing a high pressure loss especially at the tip end portion of the blade body 11, and as shown in this figure, the leading edge of the tip end portion of the blade body 11 is formed in the configuration such that the leading edge is tilted forwards in the direction of a principal axis of the axial-flow compressor, that is, tilted forwards to the upstream side of an airflow Y and also is made to advance in the direction of

rotation R of the blade body 11. In more particular, in Fig. 1(a) reference numeral 2 designates a platform (flange portion) of the blade body 11, numeral 3 designates a screw portion for fixing the blade body to a rotor shaft. In addition, as shown in Figs. 1(b) and 1(c), the tip end portion of the blade body 11 projects forwards as gradually bending from the central portion. It is to be noted that while a lower portion of the blade body 11 also projects forwards, this is for the purpose of balancing moments about a blade axis X-X of centrifugal forces at the respective cross-section profiles of the blade body, and not for the purpose of especially improving an efficiency of this rotor blade.

Referring to Fig. 2 which is a schematic view of the rotor blade, reference numeral 1 designates a blade body of a rotor blade in the prior art, numerals 21 and 24 designate equi-pressure lines of a static pressure on the blade surface, dotted line arrows indicate the direction of rise of the static pressure, and bold line arrows indicate the direction of a boundary layer adhered to the blade surface being pushed out towards the outside in the radial direction. Although the boundary layer is pushed out towards the outside in the radial direction, in the case of the rotary blade in the prior art, as shown in Fig. 2(b), equi-pressure lines 21 are directed nearly in the radial direction, hence the movement of the secondary flow of the boundary layer being pushed out is not prevented, consequently the secondary flow is directed towards the tip end portion of the blade body 1, and the boundary layer is liable to accumulate there. Whereas, in the case of the rotor blade according to the present invention, the tip end portion of the blade body 11 is made to advance, and the equi-pressure lines 24 have a distribution tilted forth towards the tip end portion of the blade body 11. Therefore, the secondary flow of the boundary layer adhered to the blade surface being pushed out by centrifugal forces, is prevented by the static pressure that is increasing towards the outside in the radial direction, and is directed towards the downstream, and so, fluid having low energy does not stagnate at the tip end portion of the blade member 11 but is pushed out towards the downstream. Thereby, an operation condition at the tip end portion of the blade body 11 can be improved, and an efficiency of the rotor blade is enhanced.

Fig. 3 is a diagrammatic view of a rotor blade, in which a white bold arrow indicates a direction of rotation of a rotor blade. Reference numeral 33 designates the position of the tip end surface of this rotor blade, and it is a plan view of this rotor blade. The tip end surface 33 of this rotor blade is displaced with respect to a tip end surface 32 of a rotor blade in the prior art, in the direction of the principal axis of the axial-flow compressor as well as in the direction of rotation, and the direction of the resultant displacement is tilted by an angle S with respect to the direction of the principal axis. This direction of resultant displacement is the skew direction, the angle S is an angle formed between the direction of resultant displacement and the direction of advance of the leading edge of the tip end portion of the blade member 11, and numeral 34 designates a skew direction line. A skew reference surface means a plane including this skew direction line 34, which plane extends nearly along the direction of height of the blade body 11, reference numerals 1′ and 11′ designate projections of the respective rotor blades onto this skew reference surface, the blade body 1 in the prior art which has no advance is depicted by solid lines, and the blade member 11 of the rotor blade according to the present invention is depicted by double-dot chain lines.

The symbol l_t represents a chord length of the tip end surface 33 of the rotor blade according to the present invention. In order to define an amount of skew, let us consider the range of the tip end portion of the blade body between the tip end surface of the rotor blade and a cross-section 35 displaced from the tip end surface towards the central portion by $l_t/2$ as an influencing range relevant to the secondary flow. A point 37 is the position of the leading edge of the cross-section profile of this cross-section 35 of the rotor blade according to the present invention on the skew reference surface. A point 36 indicates the position of the leading edge of the tip end surface 33 of the rotor blade according to the present invention likewise on the skew reference surface. The angle formed between a straight line connecting the both points 36 and 37 indicating these positions of the leading edge on the skew reference surface, i.e., an effective skew line 38 and a straight line 39 perpendicular to the principal axis of the axial-flow compressor on the skew reference surface, is here called "effective skew amount θ_s eff". Although a leading edge line 40 connecting the leading edges of the respective cross-section profiles, does not always form a straight line in practice, the thus defined effective skew amount θ_s eff is an average angle of tilting forwards to the upstream side of the leading edge of the tip end surface of the blade body 11, and a degree of influence of the secondary flow can be mostly investigated on the basis of the two parameters of the angle S in the skew direction and the effective skew amount θ_s eff defined on the skew reference surface in the above-described manner.

Fig. 4 is a diagram of data of experiments conducted with respect to the rotor blade according to the present invention. In this diagram, the angle S of the skew direction is taken along the abscissa, the effective skew amount is taken along the ordinate, an amount of improvement in a stage peak efficiency is written in % at each point, and a general tendency is depicted by contours of an amount of improvement in an efficiency. In this figure, the regions where the amount of improvement in an efficiency is 0% or more,

are the scope where an efficiency of the subject rotor blade 11 has been improved, and approximation by straight lines of the contour corresponding to an amount of improvement of 0% is the scope delimited by the following four points A, B, C and D.

	A	B	C	D
S	90°	50°	50°	90°
θ_s eff	4°	12°	21°	27°

Accordingly, in order to improve the efficiency of this rotor blade, the configuration of the leading edge of the tip end portion between the tip end surface of this rotor blade and a cross-section displaced from the tip end surface towards the central portion by $\ell_t/2$ is made such that the above-described angle S of the skew direction and the effective skew amount θ_s eff may fall in the region delimited by the aforementioned four points A, B, C and D. It is to be noted that the configurations of the leading edge and the trailing edge of the blade body 11 in the range extending from the central portion displaced by $\ell_t/2$ or more up to the hub are designed so as to smoothly continue the configuration in the influencing range, and for instance, they could be of upright type as shown in Fig. 5(a), of reversal type as shown in Fig. 5(b) or of tilt type as shown in Fig. 5(c). In general, a stage efficiency η of an axial-flow compressor exceeds 90%, accordingly the amount of improvement in an efficiency $\Delta\eta$ = 0.8% of this rotary blade, implies that (0.8/10) x 100 = 8% of a possible amount of improvement, that is, 8% of the remaining little loss has been reduced, and this is considered to be very large.

It is to be noted that the rotor blade of axial-flow machines according to the present invention should not be limited to only the above-described embodiments, but it is applicable to machines other than the axial-flow compressor, such as, for instance axial-flow blowers, axial-flow pumps and gas turbines.

As will be obvious from the detailed description above, the rotor blade of axial-flow machines according to the present invention is constructed in the above-described manner, hence fluid having low energy which is liable to stagnate at the tip end portion of the blade body can be forced to flow to the downstream without stagnating, and therefore, an efficiency of a rotor blade can be improved.

While a principle of the present invention has been described above in connection to preferred embodiments of the invention, it is intended that all matter contained in the above description and illustrated in the accompanying drawings shall be interpreted to be illustrative and not as a limitation to the scope of the invention.

Claims

1. A rotor blade of axial-flow machines, characterized by the provision of a blade body, in which a leading edge of a tip end portion tilts forwards to the upstream side and also advances in the direction of rotation, and the configuration of the leading edge of said tip end portion between a tip end surface of said tip end portion and a cross-section displaced from said tip end surface towards a central portion by 1/2 of a chord length is such that an angle S of a skew direction of the leading edge of said tip end portion in the direction of advance along the direction of rotation, and an effective skew amount θ_s eff in the direction of the leading edge of said tip end portion tilting forwards to the upstream side may fall in the region delimited by the following 4 points A, B, C and D:

	A	B	C	D
S	90°	50°	50°	90°
θ_s eff	4°	12°	21°	27°

2. A rotor blade of axial-flow machines as claimed in Claim 1, characterized in that the blade body in the range between a hub and a portion displaced from the tip end surface of the rotary blade towards the central portion by 1/2 of the chord length, is of upright type, in which the leading edge and the trailing edge of the blade body extend in the direction nearly perpendicular to a principal axis.

3. A rotor blade of axial-flow machines as claimed in Claim 1, characterized in that the blade body in the range between a hub and a portion displaced from the tip end surface of the rotary blade towards the central portion by 1/2 of the chord length, is of reversal type, in which the leading edge and the trailing edge of the blade body first tilt back towards the downstream side and then tilt forth towards the upstream side.

4. A rotor blade of axial-flow machines as claimed in Claim 1, characterized in that the blade body in the range between a hub and a portion displaced from the tip end surface of the rotary blade towards the central portion by 1/2 of the chord length, is of tilt type, in which the leading edge and the trailing edge of the blade body tilt forth towards the upstream side.

5. A gas turbine characterized in that the rotor blade of axial-flow machines as claimed in Claim 1, is used as a rotary blade of the turbine.

Fig. 1(a)

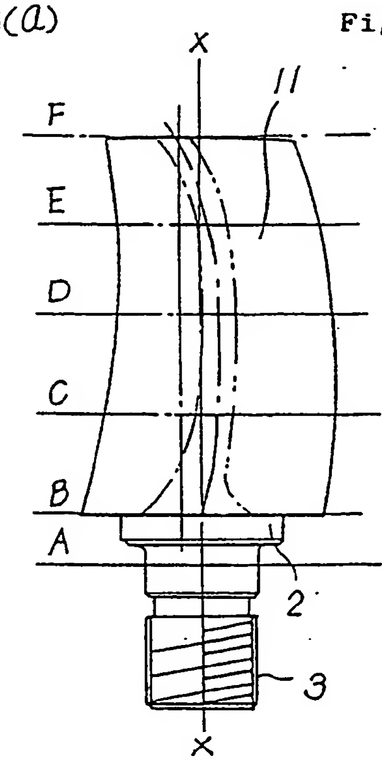


Fig. 1 (C)

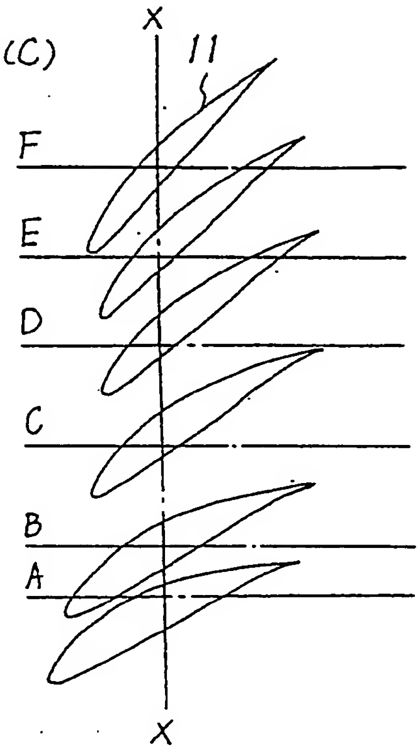


Fig. 1(b)

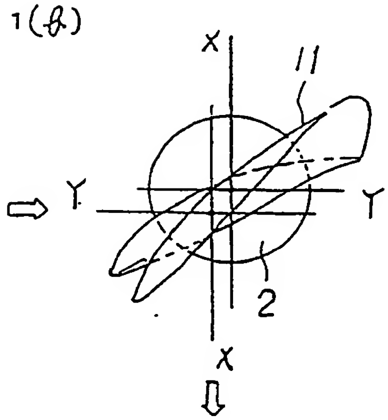


Fig. 2 (a)

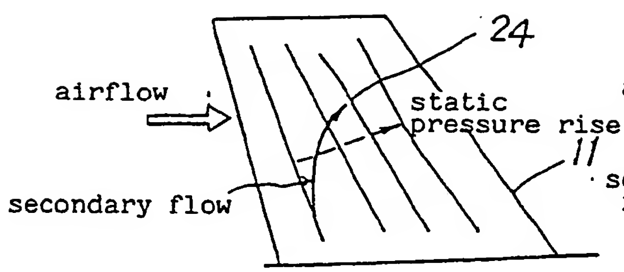


Fig. 2 (b)

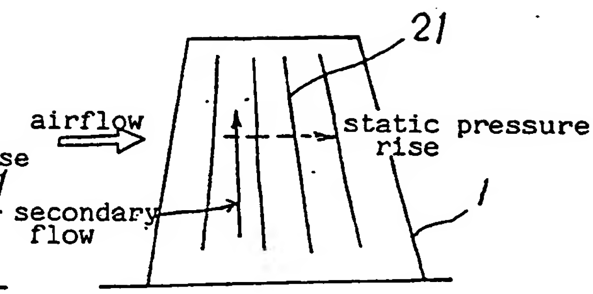


Fig. 3

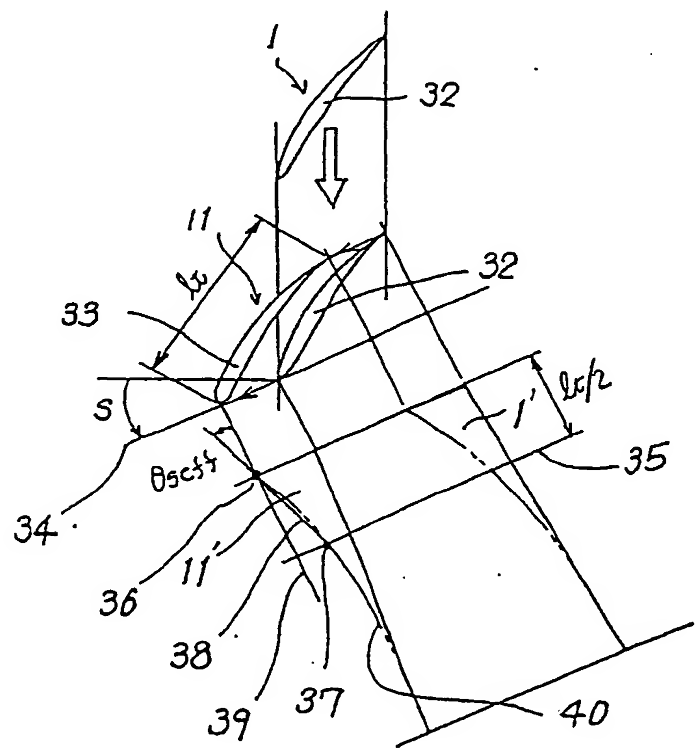
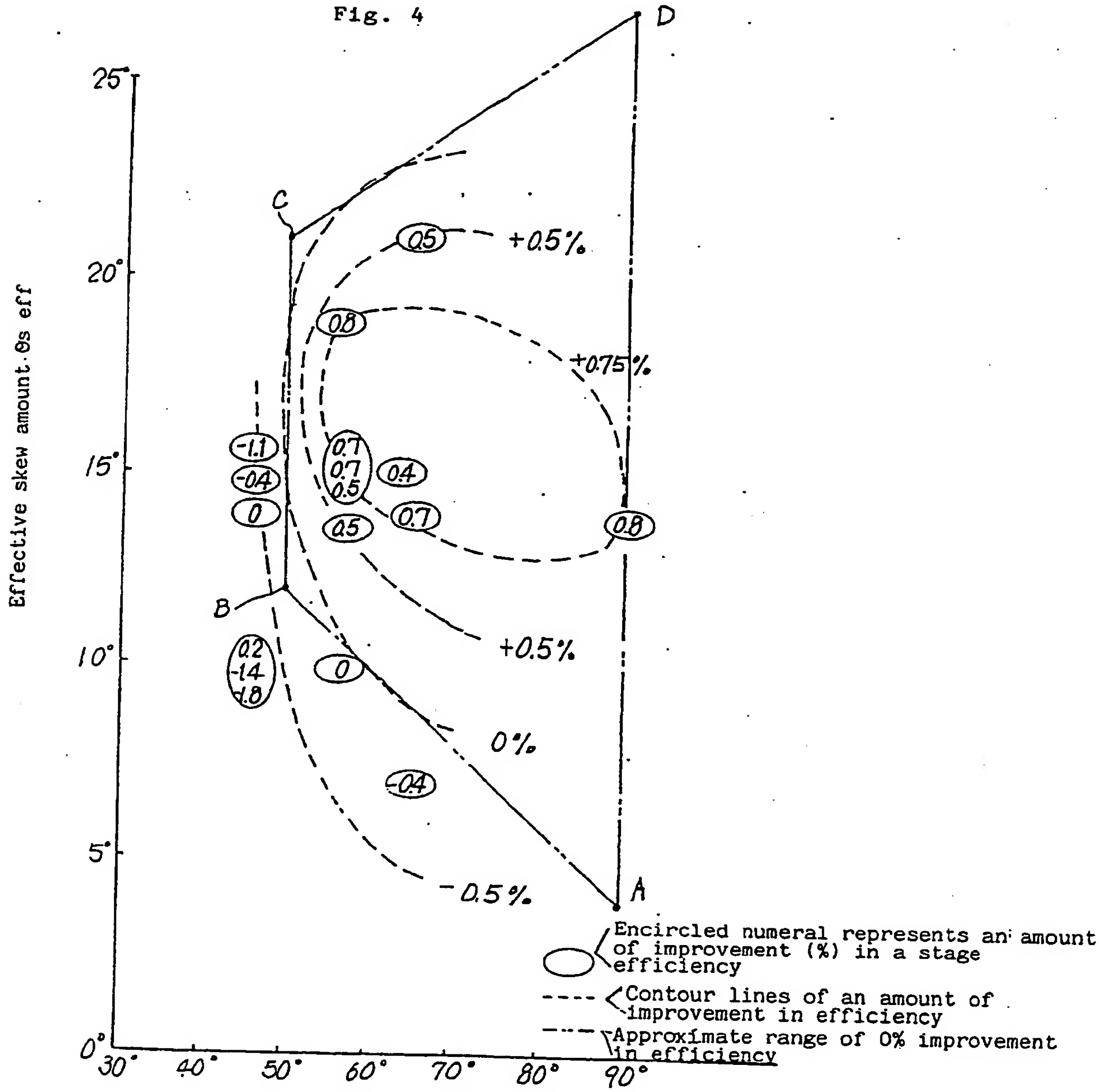


Fig. 4



Angle S of the skew direction

Fig. 5(a)

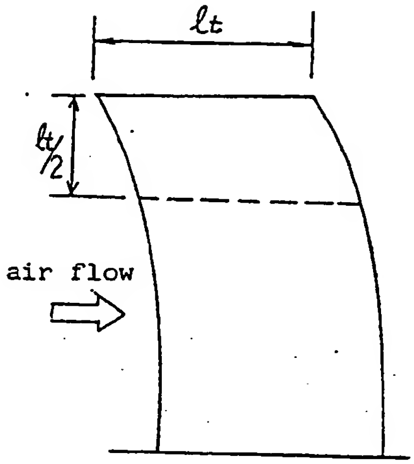


Fig. 5 (b)

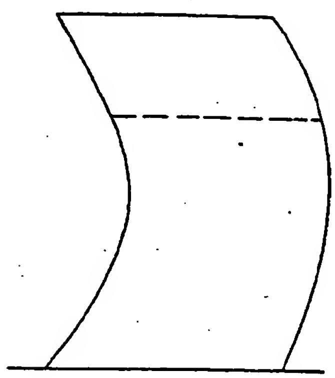


Fig. 5 (c)

Fig. 6 (a)

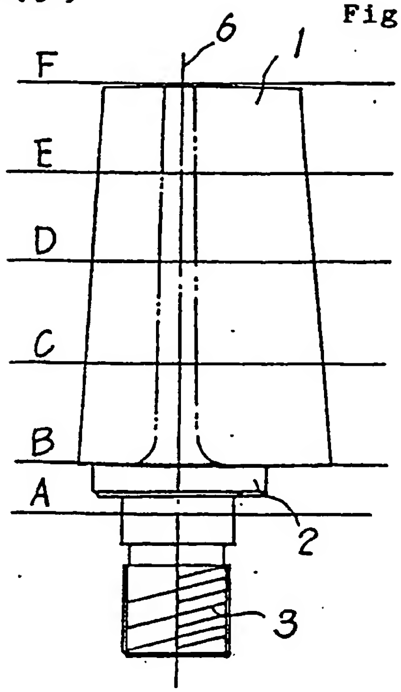


Fig. 6 (c)

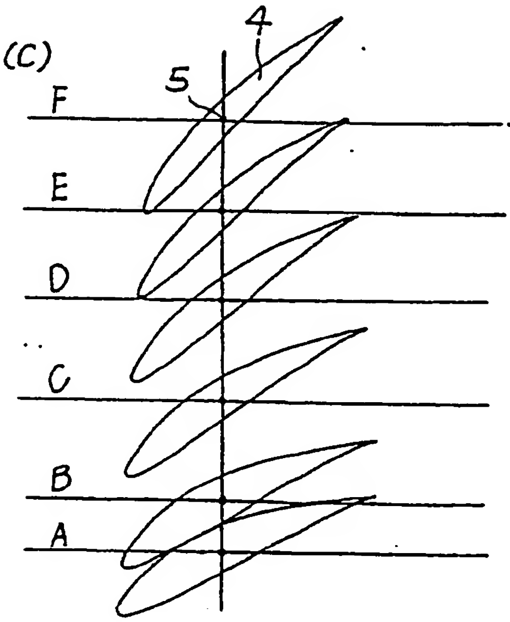
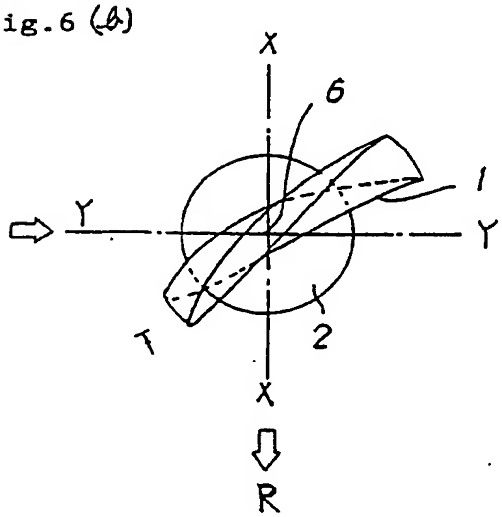


Fig. 6 (b)



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 11 9854

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	GB-A-2 151 310 (GENERAL ELECTRIC COMPANY) * page 2, lines 108 - 113; figures 1, 3, 6 *	1-5	F 01 D 5/14
Y	CH-A-5 868 41 (HITACHI LTD.) * figures 2, 3 *	1-5	
Y	GB-A-2 164 098 (ROLLS-ROYCE LTD.) * page 4, lines 120 - 128; figures 7, 10D *	1-5	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

F 01 D

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	17 January 91	CRIADO Y JIMENEZ F.A

CATEGORY OF CITED DOCUMENTS

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